10/577461
IAP20 Rec'd PCT/PTO 27 APR 2006

Electromagnetic stirring in continuous casting of metallic flat products.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from PCT Application n° PCT/FR2004/002728 based on French Patent Application n° 03 12555

BACKGROUND OF THE INVENTION

1 – Field of the invention

The present invention relates to the continuous casting of metals, especially steel. It relates more particularly to the electromagnetic stirring of flat products (i.e. of elongate cross section) while they are being cast, and relates even more precisely to the establishment in the metallic liquid pool of a particular distribution of the flows by means of applied magnetic fields.

It is reminded the general expression "product of elongate cross section" has to be understood to designate metallurgical products whose width is at least twice the thickness, especially slabs, narrow slabs, thin slabs, etc....

2 – Description of related art

Coming out in the field of continuous steel casting at the start of the seventies, electromagnetic stirring has rapidly confirmed its position as an almost indispensable tool for controlling the flows in the liquid pool undergoing solidification. It will be recalled that the principle most commonly employed is the well-known principle of MHD (magnetohydrodynamic) which, by means of a moving (rotating or travelling) magnetic field generated by a polyphase inductor, or more generally by several polyphase inductors, placed in the immediate vicinity of the cast product, drives the liquid metal with its displacement. Suitably located on the metallurgical height of the casting machine, these inductors, supplied with electrical current at an adjustable frequency, therefore allow various types of stirring modes that can be matched to the requirements of the metallurgist.

Moreover, constant progress in understanding the mechanisms of metal solidification during continuous casting has specifically demonstrated the important role played by the circulatory movements of the liquid metal for the general quality (i.e. internal soundness, surface cleanness or lack of inclusions, solidification structure, etc.) of the final solidified product .

In this regard, the movements applied to the molten metal during continuous casting may be schematically classed into two categories, depending on whether we consider the mould or, beneath it, the secondary cooling stages of the casting

machine.

The movements settled on the liquid metal by means of electromagnetic stirring within the mould, at a level where the liquid portion of the cast metal is greatly predominant, are essentially designed to control the flows in this critical area. Indeed, here, where the free surface of the cast metal is found, its internal cleanliness depends on the geometrical shape of this surface. It is also here where the first solidification skin occurs, the major importance of which being well known as regards both the surface quality of the final cast product and the control of the casting process itself.

On the other hand, by stirring the metal in the liquid pool beneath the mould, therefore in the secondary cooling zone (usually called "in the secondary"), the aim is first to improve the internal metallurgical structure of the cast product via the development of a largest equiaxed solidification, this being known to be favourable both to the micro-segregation of the alloying elements and to the absence of central porosity in the cast product, for example. Thus, electromagnetic stirring is used for the continuous casting of slabs more and more frequently whenever products that require an internal structure free of porosity have to be produced, such as for example thick plates for making boilers, or large welded pipes.

It should be only reminder here for a better understanding of the invention, as will be explained below, that it is well known, as shown by the diagram of the appended Figure 3 taken from the document FR 72/20546, to use, in the secondary cooling zone of a continuous slab casting machine, linear inductors 41, 41' placed facing each other, on either side of the large faces of the cast product, and producing transversal magnetic fields that travel over the width of the product. The aim is thus to set up, within the liquid metal, flows which essentially develop as two adjacent loops rotating in opposite directions. These loops 42, 43 are established parallel to the large faces and extend in stages along the length of the cast product on either side of a common transverse zone of driving action of the magnetic field, the flows of each loop rising along one small face and descending along the opposite small face Such a movement configuration is conventionally termed a "butterfly wings" configuration.

It is possible, as shown in the appended Figure 4 extracted from document FR 82/10844, to multiply, depending on the length of the casting machine, the transverse zones 51, 52 of the driving action of the magnetic fields. In this case, said zones are, pairwise, in opposite directions of rotation, between the closest neighbouring loops so as to generate the largest possible stirred volume for a given available stirring power. Thus, a pattern flow referred to as a "triple-zeroes configuration" is produced, this being formed from three adjacent loops rotating

pairwise in opposite directions, namely a central loop 60 located between the two transverse driving zones 51 and 52, and two outer loops 61 and 62 on either side of the central loop and rotating in the same direction.

Whatever the implementation form adopted, this can be achieved just as well with inductors placed behind the support rollers of the secondary cooling zone of the casting machine as between these rollers (FR 72/20547) or inductors housed within the actual rollers (FR 72/20546). The same also applies as regards the means of implementing the invention, which will be explained below.

Historically, it seems that the discovery of this type of movement, based on recirculation of the metal in loops set up in a plane parallel to the large faces of the slab, stems from the fact that, unlike in long products, in the continuous casting of flat products the elongate shape of the cross section of the product does not easily lend itself to the establishment of a stable rotational movement about the casting axis. The main reason probably lies in the large velocity gradients that this requires in the thickness of a product, which barely exceeds some twenty centimeters for the thickest products.

However, a staged-loop configuration of the type shown in Figures 3 and 4, which develops over the metallurgical length parallel to the large faces of the product, does not suffer from such a handicap. It also has the advantage of ensuring better heat exchange between the top and bottom areas of the casting machine. The hottest molten metal from the top is droved by forced convection downwards by the descending running 42a and 43b, while the rising running 42b and 43b seed the top with crystallites of solidified metal that have collected in the bottom, thus favouring the early development of extensive uniform equiaxed solidification from the periphery right to the centre of the cast product. However, these loops 42, 43 cannot be developed too vigorously near the top as one would wish, owing to the risk of disturbing the free surface of the metal in the mould. At the present time, it is known how much the preservation of the fragile hydrodynamic equilibrium of the in-mould flows prevailing at this level of the mould is necessary for obtaining a good quality of the surface, of the sub-skin and of the core of the cast product.

Precisely, the introduction of the metal to be cast via the top of a mould using a submerged nozzle having lateral discharge outlets opening onto the narrow faces of the mould has become virtually general practice at the present time, replacing the straight nozzle with a single axial discharge, consequently reserved practically only for long products. A major advantage obtained over in-mould flows lies in the fact that, as shown by the diagram in Figure 1 appended hereto, by means of a rebound effect onto the narrow faces of the mould, the jet of hot liquid metal coming out from each lateral hole 27, 27' in the nozzle 26 is therefore spread out naturally into two fractions. A main fraction 21 is directed downwards, in the

direction of extraction of the cast product. The other fraction 22 is reflected upwards so as to provide, near the free surface 23 of the in-mould metal, the enthalpy needed to prevent the phenomenon of cast metal solidifying at the meniscus, which are very often the cause of drastic stoppages of the casting process. The aim is thus to produce, in the mould, a circulation mode called "double roll" as opposed to the "single roll" mode.

The latter mode, shown in Figure 6, is firstly manifested by the phenomenon of metal rising up towards the meniscus upon being discharged from the outlets in the nozzle, very often resulting from an injection of argon to prevent clogging of the nozzle from the casting tundish located above it. This first upward rise is then continued by a surface current towards each narrow face, and after by a going down flow along the latter. In this way, a velocity map is quickly established in the mould, in which the velocities are generally directed downwards in the direction of extraction of the product, with the absence of the upper roll 22 for supplying "hot" metal to the meniscus.

However, the "double roll" mode lasts during casting only if the casting conditions (casting speed, width of the slab, depth of immersion of the casting nozzle, flow rate of anti-clogging argon, etc.) lend themselves thereto. Random transitions in "single roll" mode may appear during the actual course of casting if these conditions fluctuate, which in fact corresponds to a general case.

In addition, an essential aspect for controlling the in-mould "double roll" flows, lies in the preservation within the mould of a "left-right" symmetry of the re-circulating movements at the meniscus on either side of the nozzle. This is because it is known that the occurrence of "left-right" asymmetries is the grounds of oscillations in the metal bath that may result in unacceptable rolling of the surface, well known to the operator standing on the casting platform. This means that care must be taken to ensure that the partial recirculation flows 22, 22' near the top are, above all, steady over time in order to avoid the occurrence of "left-right" asymmetries. These ascending circulation, while still being thermally effective enough to deliver the desired heat to the meniscus, must however not be too intense from the hydrodynamics standpoint in order to avoid excessive agitation of the line of first solidification 25 that forms around the border of the meniscus against the cooled copper wall of the mould. The regularity of this line of first solidification is in fact the warrant of uniformity of formation of the first skin in the top of the mould, without which there is inevitably a risk of break-outs beneath the mould by encrustations of slag or by local thinning of the thickness of the solidified skin.

Stated more simply, by casting with a submerged nozzle having lateral discharge outlets, it is possible to achieve, over the course of any one casting run, randomly

or, in any case, not necessarily desirable, in-mould flows that are either of the "double roll" type, or of the "single roll" type, or unstable flows owing to "left-right" asymmetries.

It is in particular because of these difficulties in controlling flows in the top area of continuous casting machines that electromagnetic stirring systems have more recently appeared that act in the mould, already on the lateral discharge jets coming from the nozzle. As the diagrams of the appended Figures 2a and 2b show, which are extracted from document JP 1534702, magnetic fields moving horizontally are produced by multiphase linear inductors 30a, 30b and 30a', 30b' placed along the large faces of the mould 32 facing the discharge path of the metal jets on either side of the nozzle 31. By adjusting the direction of travel of the fields, it is then possible to slow down the current of said jets of metal (counter-current travel of the fields, going from the small face to the nozzle (Figure $2b_1$) or, on the contrary, to speed it up (co-current travel in the direction going from the nozzle towards the small face (Figure $2b_2$). In principle, this allows the amount of enthalpy supplied to the surface of the cast metal to be adjusted, for example according to the casting conditions, without excessively disturbing the in-mould flow mode that has to be preserved as a matter of priority.

The above rapid review of the prior art therefore clearly shows the separation, if not the conflict, that exists when casting products having an elongate cross section (like flat products) between the stirring of the metal in the mould on the one hand and the stirring in the secondary cooling zone, on the other.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is specifically to overcome such a handicap. Stated another way, applicable to the continuous casting of flat products, particularly slabs, the object of the invention is, via a studied overall stirring movement of the molten metal over the metallurgical length, to provide good exchange of still-liquid metal in both directions between the secondary cooling zone and the mould. This will consequently achieve thermal and chemical uniformity between the top and bottom of the pool of cast liquid metal without disturbing the in-mould flow mode and, where possible, without correspondingly being deprived of the cumulative beneficial effects specific to stirring in the mould and to stirring in the secondary cooling zone respectively.

One complementary object of the invention is to help to improve the metallurgical quality of steel grades that it is desired to produce with good internal quality, such as grades for thick plate or for large welded pipes, ferritic stainless steel, or silicon electric steel.

Another complementary object is to be able to vary the flows in the secondary

cooling zone in order to use them level with the casting jets emanating from the nozzle, either as an accelerating agent or on the contrary as a braking agent for the metal entering the mould, or else as a means for counteracting the "left-right" asymmetry tendencies of the metal movements within the mould.

With these objectives in mind, the subject of the invention is a method of electromagnetic stirring in the secondary cooling zone of a plant for the continuous casting of slabs, or other similar flats products, the mould of which is provided with a submerged casting nozzle having lateral discharge outlets directed towards the narrow faces of the mould, which stirring method is implemented by means of travelling magnetic fields generated by multiphase inductors placed near the cast metal, characterized in that a longitudinal liquid metal flow is forcibly established in the said secondary cooling zone, said forced flow being localized in the middle region of the cast product as two opposing collinear streams.

This one naturally establishes a circulation of the entire liquid metal in the secondary, having the configuration of a "four-leaf clover" with two upper lobes and two lower lobes, the upper lobes of which extend into the mould right up to the level of the jets emanating from the discharge outlets of the casting nozzle.

According to a implementation form of the invention, these two longitudinal opposing collinear streams in the central part of the product, which move away from each other, are created in such a way that the two upper lobes which extend into the mould right up to the level of the jets emanating from the discharge outlets of the casting nozzle merge concurrently with the said jets in order to reinforce them.

According to another implementation form, these two longitudinal opposing collinear streams in the middle part of the product, which converge on each other, are created in such a way that the two upper lobes that extend into the mould up to the level of the jets emanating from the discharge outlets of the casting nozzle are superposed counter-currently on the said jets in order to slow them down.

According to one particular embodiment of the method, the location of the longitudinal flow in the secondary is shifted laterally towards one or other of the narrow faces of the cast product so as to counteract the "left-right" asymmetry tendencies of the metal movements within the mould.

According to one method of implementation, the longitudinal metal flow in the middle region of the cast product is created as two opposing collinear streams by means of collinear moving magnetic fields that travel longitudinally in the said central region, either coming closer together, or further apart.

According to the preferred implementation, the longitudinal metal flow in the middle region of the cast product is created as two opposing collinear streams by means of collinear moving magnetic fields that travel transversely over the width

of the cast product, either coming closer together from the edge towards the centre of the cast product, or moving further apart from the centre towards the edge of the cast product.

According to another preferred implementation form, the travelling magnetic fields are generated by means of multiphase linear inductors that are placed facing the large facess of the cast product.

As another implementation form, the inductors are supplied with electric currents of different intensities, so as to vary, in a different manner, the action on the two opposing collinear metal streams created by the travelling magnetic fields that they generate.

The term "collinear" applied to the travel of the fields or to the metal flows should be understood to mean that the magnetic fields, or alternatively the streams of metal, do not travel parallel to one another but instead travel along the same line, in the manner of two collinear vectors as opposed to two parallel vectors.

As will have been understood, the invention consists, in its principal basics, in creating, in the secondary cooling zone, a "stirring cross" having two transverse branches and two longitudinal branches. The transverse branches (or horizontal branches if it is assumed that the casting axis is vertical) develop across the width of the cast product and the two longitudinal (or vertical) branches develop within the central region (usually the axial region) of the cast product.

Indeed, this "stirring cross" in the secondary zone of the cast machine leads to the development of a recirculation flows in the liquid pool in the form of a quadrilobate configuration, and then creates an global configuration of the movements that also get to the mould region, such that the aforementioned objectives intended by the invention are reached.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The invention will be more clearly understood and other aspects will become more clearly apparent in the light of the description that is given with reference to the appended plates of drawings in which:

- Figures 1 to 4 are representative of the prior art, already considered above.

More precisely:

* Figure 1 is a standard diagram showing, in summary form and as a vertical central section parallel to the large faces of the mould, the known map of the circulatory movements of the liquid metal entering a mould for the continuous casting of slabs via a submerged nozzle provided with lateral discharge outlets that open towards the narrow faces;

* Figures 2a, $2b_1$ and $2b_2$ are diagrams, in two views (on the left in perspective and on the right in cross section), of known in-mould electromagnetic stirring

modes for the continuous casting of slabs with a submerged nozzle having lateral outlets (cf. Fig. 1) by means of linear multiphase inductors located on either side of the nozzle on each large face of the mould and producing traveling magnetic fields that travel horizontally in opposed directions, pairwise, over the same large face, either in the same direction as the discharging jet of metal to which the field is applied (Fig. $2b_2$), or in the opposite direction (Figs $2b_1$ and 2a);

* Figure 3 is a simplified diagram showing, in perspective, a slab during continuous casting as it can be seen in the secondary cooling zone of the casting machine. This zone is provided with a pair of linear inductors facing each other on each side of the product over the width of the latter and generating a magnetic field gliding horizontally so as to produce a "butterfly wings" shaped electromagnetic stirring mode known for example from the aforementioned document FR 7220546;

* Figure 4 is a diagram similar to the previous one in figure 3, but showing a "triple roll" electromagnetic stirring mode, such as that produced for example by implementing the teaching of the aforementioned document FR 8210844;

- The other figures, numbered 5 to 9, are specific to the invention.

More precisely:

* Figure 5 is a general diagram, seen in axial vertical section parallel to the large faces of a mould for the continuous casting of slabs, the said mould being provided with a submerged nozzle having lateral discharge outlets that open towards the narrow faces, and showing the principle of a global stirring in the form of a four-leaf clover in the secondary cooling zone according to one of the implementation modes of the invention in which the opposing longitudinal streams move away from each other, and the map of the circulatory movements of the liquid metal that results therefrom within this zone just below the mould;

* Figure 6 is a diagram similar to that of Figure 5, but in the case in which the in-mould flow mode is no longer of the "double roll" type but is of the "single roll" type;

* Figure 7a is a diagram which, on the basis of a repeat of the Figure 5, shows by means of implementing the stirring in the form of a four-leaf clover by means of linear inductors having a horizontally travelling magnetic field;

* Figure 7b is a diagram similar to Figure 7a, but illustrating another embodiment of implementing the invention, this time using linear inductors having a vertically travelling magnetic field;

* Figure 8 is also a diagram which, on the basis of a repeat of the Figure 5, illustrates a preferred embodiment of the invention, setting up a complementary in-mould flow in "double roll" mode by means of linear inductors generating a horizontally travelling field, which act directly on the jets of metal discharging from the outlets in the casting nozzle; and

* Figure 9 illustrates another implementation of the invention which consists in creating opposing longitudinal streams of metal in the middle part of the cast product, these no longer being divergent but convergent.

DETAILED DESCRIPTION OF THE DRAWINGS

It should be reminded that Figures 1 to 4 were used to support the explanation of the prior art already made at the beginning of this document. They will therefore not be referred to again in the following text.

In Figures 5 to 9 representative of the mode of stirring in the secondary cooling zone specific to the invention in these two implementation modes (divergent or convergent metallic streams at the middle), the travelling magnetic fields, just like the linear inductors that produce them, are represented by thick vertical or horizontal arrows. The convective movements produced are themselves shown by their main paths in the form of lines carrying arrowheads indicating the direction of circulation of the movement over the carrying path. The solid lines represent active convection zones, and therefore circulation zones subjected to the action of the travelling magnetic fields. The broken lines represent the passive convection zones, in other words recirculation zones which are necessarily complementary to the active zones in order to close the loop of the movements.

In these figures, the same elements are denoted by identical references. Where necessary, in order not to unnecessarily overload certain figures, recurrent references have not been indicated so as to make the essential elements of the invention shown in these figures clearer.

Each of the figures shows a continuous slab casting mould 1 followed beneath it by the secondary cooling zone 2 of the casting machine, here intentionally shown without the support rolls in order not to unnecessarily reduce the clarity of the drawing. Since the views are in a plane parallel to the large faces of the mould, only the narrow faces are visible at 3 and 3', these faces determining the narrow sides 18, 18' of the cast product 6. Since the large faces are in the plane of the figures, they are not referenced in the figures. Moreover, for greater clarity, the reference 6 will denote either the cast slab itself or its still-liquid core, more generally called "liquid pool".

A submerged nozzle 4 centred on the casting axis A (which is coincident here, as is conventionally the case, with the longitudinal axis of the cast product) supplies the mould with molten metal from a tundish (not shown) located above it. This nozzle is provided with lateral discharge outlets 5 and 5' each facing one or other of the narrow faces 3 and 3' respectively. The size of the cast product is determined by the inside dimensions of the mould that defines the casting space into which the molten metal enters in the form of jets 7, 7' discharging from the

outlets of the nozzle 4, conventionally along a more or less horizontal mean direction, or slightly inclined downwards. The cast product thus advances from the top, level with the meniscus 8, downwards, in the extraction direction of the casting machine, along the vertical or along a curved path, in a plane orthogonal to that in the figures, at an extraction rate (casting rate) usually of the order to one metre per minute. As it advances, the product progressively solidifies from its periphery up to the centre, by extraction of its internal heat, firstly into the mould 1 in contact with the cooled copper walls and then in the secondary cooling zone 2 under the effect of the water spray rails.

It will be reminded that the metallurgical length (or depth of the liquid pool) is conventionally defined as the difference in the dimensions along the vertical between the level of the free surface of the cast metal in the mould (or meniscus) and that of the bottom of the liquid pool below the secondary cooling zone, at the point where the finishing solidification fronts, which develop over each of the large faces of the cast product as the solidification progresses, meet.

Located arbitrarily along the longitudinal axis of the product (which is coincident with the casting axis A), about 3 or 4 m below the meniscus 8, and therefore within the secondary cooling zone 2, is a point P that will be termed the centre of the "stirring cross" 9 which represents the specific creation of the invention. This stirring cross 9 is a cross with four branches, these being collinear in pairs, namely two longitudinal (and here vertical) branches 10a, 10b, forming a pair aligned with the casting axis A, and two transverse (and here horizontal) branches 11a, 11b forming a pair that develops over the width of the cast product. In each of the two branches of any one pair, the liquid metal stream circulates therein, pairwise, in opposite directions. Moreover, the circulation of the stream in one pair is in the opposite direction to that of the other pair.

Owing to the necessarily “finite” dimensional character of the cast product, these branches, as may be seen, are as it were connected together by recirculation loops in order to form an overall flow that develops in the plane of the large faces of the cast product in a four-leaf clover configuration, the leaves constituting the lobes L1, L2, L3, L4, the upper two of which, L1 and L4, extend up to the mould level with the discharge jets 7 and 7’.

Thus, in the stirring mode shown in Figures 5 to 8, the pair of vertical branches is on a “divergent” convection type - the streams of metal move away from each other from the centre P. One, 10a, flows away towards the mould 1 lying above it while the other 10b flows away downwards, in the direction of extraction of the cast product, towards the closure point of the liquid pool. In the horizontal pair 11a, 11b, the convection of the metal is therefore of a “convergent” type - the metal streams flow towards each other in the direction of the centre of confluence

P, flowing from the small faces of the product towards the longitudinal axis A.

As already mentioned, the metal streams that form these branches are created by travelling magnetic fields, which are themselves generated by linear inductors placed in the immediate vicinity of the cast product facing these large faces (preferably both sides). Of course, it is unnecessary for the two pairs of branches to be simultaneously activated by the magnetic fields. Only one may be activated, for example the vertical branches 10a, 10b, the other branches 11a, 11b then becoming, of course, the site of recirculation by reaction, since the centre P acts as a current passage node that maintains the mass flow rates and the movement quantities, and vice versa.

However, in this first stirring mode of the invention, it is important for the vertical branches 10a and 10b to flow away from each other, as shown in Figures 5 to 8. In the upper lobes L1 and L4 that are close to the mould, the metal rises along the centre and descends along the narrow faces, the opposite being the case in the lower lobes L2 and L3.

Under these conditions, it turns out that the implementation of the invention maximizes the exchange of metal material between the bottom and top of the liquid pool. Firstly, the circulation of metal in any one lobe takes place in the direction of rotation opposite to that established in the two closest neighbouring lobes. Secondly, since the force of the casting jets 7 and 7' is then systematically reinforced by the co-current rising central flux 10a, the recirculation loops L5 and L6 in the mould near the meniscus 8 are in turn reinforced. Consequently, the "double roll" mode L5, L1, L4 and L6 present within the mould are thus additionally stabilized.

It will therefore be readily understood that any liquid metal element (conceptually isolated at an arbitrary point along the metallurgical length) will have a high probability of being present, by randomly following the successive ascending or descending running, at least once in the mould before re-descending if it is initially in the secondary cooling zone, and vice versa if it is initially chosen to be in the mould, it being understood that overall the element will necessarily undergo a mean downward displacement in the direction of extraction with a mean speed equal to the casting speed. In other words, this implementation of the invention maximizes the exchange of molten metal material between the hot zones of the mould and those cooler zones of the secondary cooling zone and does so by reinforcing, in the mould, the known means suitable for stabilizing the "double roll" mode.

Such an exchange contributes in particular to better removal of the excess heat and to the initiation of early and ample equiaxed solidification of the metal, without any risk of disturbing the in-mould flow mode, by instead reinforcing the stability

of the "left-right" symmetry of the movements on either side of the nozzle, and to do so whatever the local mode present, namely "double roll" (cf. Fig. 5) or "single roll" (cf. Fig. 6), and therefore counteracting the natural random tendency for transition from one mode to the other.

As already mentioned, the branches 10 and 11 of the stirring cross 9 are generated by the action applied at these points by travelling magnetic fields. The lines of force of these fields are orthogonal to the surface of the cast product, or at the least have a predominantly orthogonal component, in order to maximize the electromagnetic coupling with the liquid metal.

It is well known that such fields can be easily produced by conventional multiphase linear inductors.

Figure 7a illustrates a first implementation of the invention in which two identical linear inductors 12 and 13 are placed horizontally at the same vertical level on the casting machine (collinear inductors) on either side of the casting axis and mounted in opposition so as to create collinear magnetic fields travelling transversely over the width of the cast product, from the small sides 18, 18' towards the centre.

These inductors are advantageously designed so as to each generate a travelling magnetic field, in an active convection branch (11a or 11b), having a length equal to slightly less than one half of the half-width of the cast slab 6.

In this case, the driving force for the stirring is given by the convergent transverse branches 11a, 11b of the stirring cross, and the longitudinal diverging flows 10a, 10b are then obtained after passing the point of confluence P.

Figure 7b illustrates a second type of implementation of the invention, equivalent to the previous one as regards the effects obtained. According to this second implementation, the linear inductors 14 and 15, mounted collinearly but in opposition, are placed vertically along the casting axis. In this way, the vertical branches 10a and 10b (the presence of which within the secondary is at the very basis of the invention) are this time activated directly, the upper inductor 14 then generating a magnetic field travelling towards the top of the casting machine in the direction of the mould, the lower inductor 15 producing a field that travels downwards towards the bottom of the pool.

Figure 8 illustrates a preferred embodiment of the invention. This consists in converting the upper edge of the upper re-circulating lobes L1 and L4 (which reinforce the casting jets 7 and 7') into active convection zones. To do this, added to the pair of inductors already present in the secondary cooling zone, for creating the stirring cross 9, are two additional linear inductors 16, 17 generating horizontally travelling fields, these two inductors being placed collinearly on either side of the nozzle 4 level with the jets of metal 7 and 7' discharging from the

outlets 5 and 5' and travelling co-currently with the said jets, from the nozzle towards the narrow faces 3, 3' of the mould 1. The effect of convergence between the jets and the central flow rising up from the bottom is thus further enhanced, and consequently the local in-mould "double roll" mode likewise.

Figure 9 is similar to Figure 5 but is distinguished therefrom however in an essential manner by the fact that the directions of circulation of the metal in each of the four branches of the cross 9 are reversed. The Figure 9 thus illustrates the second main implementation form of the invention, which consists in creating opposing longitudinal collinear streams 20a, 20b in the central part of the cast product 6, which this time converge on each other towards the point P so as to provide an overall circulation of the liquid metal that is extended, in the mould 1, by flows rising along the small sides 18, 18' up to level with the jets of metal 7, 7' emanating from the discharge outlets 5, 5' in the nozzle, which they oppose as a counter-current in order to brake them.

Overall there is again a stirring configuration in the secondary cooling zone consisting of four lobes L1 to L4, the loops of which therefore rotate in opposite directions to those of the first implementation. However, because of the opposing effect of the upper lobes L1 and L4 on the jets 7 and 7', the downward return flows of the metal in the central part of the liquid pool are less channelled and confined, instead much more diffuse and dispersed in that section of the product than in the said first variant.

It will be understood that these two main implementation modes are in fact only two different and complementary facets of the same invention and may be jointly present when implementing the stirring method. It will in fact be easy to modify, in terms of dynamics, the directions of travel of the acting magnetic fields, for example by reversing the polarities of the inductors that produce them, so as to be able, on demand, to brake or accelerate the running of the casting jets 7, 7' by acting on the stirring localized in the secondary cooling zone, far away from these jets.

It will therefore be seen that a key advantage of the invention is that it ensures good top/bottom exchange in the liquid pool while still being able to act remotely on the casting jets in the mould, and to do so by a simple and unsophisticated arrangement of the electromagnetic stirring equipment, the components of which are widely available commercially.

As will have been understood, the invention consists, in summary, in judiciously using the electromagnetic stirring means currently available in order to make, in the secondary cooling zone, a cut in the long direction of the product into two juxtaposed strands and, in each strand, to install a "butterfly wings" type stirring configuration. By doing this, an overall flow system is created in the secondary

cooling zone consisting of four lobes, the core of which is the "stirring cross" 9 with its centre P.

Preferably, for obvious reasons of symmetry, this division into two strands will take place at mid-width of the cast product, that is to say along the longitudinal axis of the latter, as this axis generally coincides with the casting axis.

This said, it will be sufficient to unbalance the stirring forces between the two transverse branches 11a, 11b, for example by a differential adjustment of the intensities of the electrical currents supplying the inductors 12, 13 in order for the central position of the centre P to be shifted laterally towards one narrow face, 5, or towards the other, 5', and thus to obtain a more selective effect on the in-mould movements on one side of the nozzle than the other.

Likewise, a similar imbalance in the vertical branches 10a, 10b will make it possible, using given stirring equipment, to cause an upward or downward displacement from the centre P of the stirring cross without having to modify the position of this equipment on the casting machine.

If it is desired to be able to use both these options of adjusting the position of the centre P of the stirring cross, it will admittedly be necessary to provide the secondary cooling zone with equipment consisting of four inductors so as to be able to electromagnetically activate each of the four branches 10a, 10b, 11a and 11b.

Whatever its mode of implementation, the invention provides overall stirring of the metal over the metallurgical length capable of ensuring both thermal and chemical uniformity between the top and bottom of the liquid pool without correspondingly being deprived of the beneficial effects specific to stirring in the mould and stirring in the secondary cooling zone respectively, and without disturbing, indeed by stabilizing, the local flow mode in the mould.

It goes without saying that the invention is not limited to the examples described above, rather it extends to many implementation forms or equivalents provided that its definition, given in the claims that follow, is respected.

Thus, for example, although the linear inductors to be used conventionally have a plane structure, this arrangement is only a preferred one. Also suitable may be inductors of curved shape in order to better match the shape of the surface of the slab at the point where they are placed along the metallurgical length.